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Carole Campbell

THE EFFECTS OF EARMUFFS AND HEARING IMPAIRMENT ON WORD DISCRIMINATION IN NOISE

Carole Campbell
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Central Institute for the Deaf
Advisor: William W. Clark, Ph.D.
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ABSTRACT

CID W-22 (PB) word lists were presented in the presence of a broad band noise in a reverberant test booth to normal-hearing and hearing-impaired listeners. Word discrimination performance with two different circumaural earmuffs under two noise conditions was compared. Results indicated that, for normal-hearing listeners, wearing the EAR Ultra 9000 or the Noisefoe Mark II earmuff caused a significant decrease in word discrimination ability in low levels of ambient noise (36-77 dBA) with a high signal-to-noise (S/N) ratio. Higher word discrimination scores were obtained with the Ultra 9000 muff as compared to the Mark II. As the noise level increased (low S/N), the performance while wearing either earmuff did not significantly differ from the "no muff" condition. In high levels of ambient noise (85 dBA), earmuffs did not produce significant decreases in word discrimination ability for the two subject groups when compared to the non-protected condition. Hearing-impaired subjects with a high tone loss performed more poorly in low and high levels of ambient noise both with and without earmuffs as compared to normal-hearing subjects. The type of hearing protector and its attenuation in the higher frequencies may be important factors to consider when selecting a suitable hearing protection device. For hearing-impaired individuals, the selection of a device that offers minimum attenuation of the speech spectrum and yet adequate protection is preferred.

INTRODUCTION

The goal of any hearing conservation program is to protect an employee's hearing by reducing the exposure to potentially hazardous noise environments. One way of protecting the hearing is to directly eliminate the noise source itself, but because of its cost effectiveness, the utilization of personal hearing protection devices has become the chosen method for many industrial hearing conservation programs. The purpose of a hearing protector is to reduce the acoustic transmission of air-borne sounds to the cochlea.

Acceptance by the employee of the hearing protector and its proper use are of utmost importance to the success of the hearing conservation program. Wilkins and Martin (1982) reviewed many studies which showed that employees chose not to use hearing protection devices because they interfered with the detection of warning signals. Other studies (Berger,1980; Kryter,1985; Lindeman,1976) discussed the difficulties encountered in speech communication while wearing hearing protectors.

Previous studies have suggested that hearing protectors either have no influence on or improve speech intelligibility in normal-hearing subjects when tested in levels of noise greater than 80 dBA (Kryter,1946). Other studies which investigated the performance of hearing-impaired subjects found that speech intelligibility was improved when earmuffs or earplugs were used (Lindeman, 1976; Coles and Rice, 1965).

Berger (1980) pointed out that a hearing protector provides more attenuation with increasing frequency, but that the noise and speech signals are attenuated equally at a particular frequency. Thus, the signal-to-noise ratio remains constant as the overall level of the sound is decreased. According to Lindeman (1976), this reasoning should indicate that using hearing protectors in a noisy environment should not affect communication. Lindeman, however, noted that the situation is different in practice. Especially in the case of individuals with high-frequency sensorineural hearing loss, the addition of high-frequency attenuation may render speech information present in some sounds inaudible.

The purpose of the present study was to investigate the effects of earmuffs and hearing impairment on word discrimination ability in low (36-77 dBA) and high levels of ambient noise (85 dBA). In particular, differences between normal-hearing and hearing-impaired individuals with a moderate or severe high frequency hearing loss were evaluated. A second objective was to compare the performance of two circumaural conditions in normal-hearing and hearing-impaired listeners.

METHOD

Subjects

Two groups of subjects were used in this study. One group consisted of 8 normal-hearing young adults having air-conduction threshold levels (HTLs) less than or equal to 25 dB HL (ANSI-1969) for the frequencies of 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. These subjects were graduate students or employees at the Central Institute for the Deaf. There were 2 males and 5 females ranging in age from 20 to 27 years. The means and standard deviations of their hearing threshold levels are listed in Table 1 and plotted in Figure 1.

The second group consisted of 9 hearing-impaired adult males ranging in age from 38 to 70 years with a mean age of 58.7 years. These subjects were chosen from the Central Institute for the Deaf Clinic patient population on the basis of their hearing threshold levels (HTLs). These subjects had air-conduction HTLs less than or equal to 25 dB HL for the frequencies of 250, 500, 1000, and 2000 Hz and HTLs greater than or equal to 45 dB HL for the frequencies of 3000, 4000, 6000, and 8000 Hz. The means and standard deviations of the hearing threshold levels (ANSI-1969) for the hearing-impaired group are represented in Table 2 and are also graphed in Figure 2. Five of these subjects indicated a positive history of occupational noise exposure. All subjects were white, native English speakers.

Materials

Instrumentation and Calibration

1. Audiometry

Pure-tone air conduction threshold testing was performed in a sound-isolated test room which had a suitable acoustic environment (ANSI-1977) for threshold measurements. The pure-tone test signal was delivered by a portable Beltone Model 110 audiometer and transduced by Telephonics TDF 50P earphones with Telephonics P/N 510C017-1 cushions. The audiometer was calibrated with a General

Radio Type 1565-A sound level meter and a Grason-Stadler 9-A Type earphone coupler prior to and after all testing.

2. Speech Discrimination

Figure 3 represents a schematic diagram of the electronic equipment. The output of a noise generator (General Radio 1382) was fed to an attenuator set (Hewlett Packard Model 350B). The broad band noise was amplified (Crown D-150A Series II) and played through a loudspeaker (JBL Model 2482 and 2343, horn and driver). The speech output from an audio cassette tape deck (Technics RS-915) was fed to the second channel of the amplifier and was delivered to a separate loudspeaker (KLM Model Six). The frequency response of the KLM loudspeaker was approximately 80-20,000 Hz. The frequency response of the audio cassette deck was 40-14,000 Hz (+/- 3 dB).

The earmuffs used in the study were the EAR Ultra 9000 and the Mine Safety Administration Noisefoe Mark II. The EPA Noise Reduction Rating (NRR) for each earmuff is given in Table 3. The NRRs of the Ultra 9000 and Noisefoe Mark II earmuffs are 15 dB and 25 dB, respectively. The mean real-ear attenuation values provided by the manufacturer for the Ultra 9000 muffs (ANSI S3.12-1984) and the Mark II muffs (ANSI S3.19-1974) are also listed in Table 3.

Stimuli

Acoustic calibration of the broad band stimulus was carried out in the sound field with a sound level meter (Bruel & Kjaer Type 2231, microphone Type 4155) held at a position in space corresponding to the subject's pinnae. A 1/3-octave band filter set (Bruel & Kjaer Type 1625) was used to measure the spectrum of the broad band noise. Figure 4 represents the sound pressure levels (dBA) measured in 1/3-octave bands between 100 and 10,000 Hz. The bandwidth of the white noise was approximately 500-4000 Hz.

The speech stimuli were also calibrated with the B&K Type 2231 sound level meter held at a position corresponding to the subject's pinnae. Peak sound pressure levels (dBA), as measured in the field, were averaged for the recorded CID Auditory Test W-22 word lists. Several versions (A, B, C, D, E, and F) of lists 1, 2, 3, and 4 were used.

Procedure

Figure 5 represents a schematic diagram of the testing booth. All data for this experiment were gathered with the subject seated in a single-walled booth (IAC Model 403) lined with 3/4" masonite to make it reverberant. The subject was seated in the middle of the test booth (1 meter from each loudspeaker) facing the KLH loudspeaker (loudspeaker A).

Two experiments were conducted. Experiment I consisted of testing normal-hearing and hearing-impaired subjects' word discrimination ability in the various earmuff conditions: 1) EAR Ultra 9000 2) MSA Noisefoe MarkII and 3) no earmuff. The recorded W-22 word lists were presented at an average peak sound pressure level of 68 dBA while the level of the broad band noise was varied from 36 to 77 dBA (i.e., signal-to noise ratios varied from -9 to +32 dB). The subjects were instructed to give a written response to the test stimuli. Word discrimination scores (% correct) were calculated for each ear protection condition at the various signal-to-noise ratios (S/N).

Experiment two also utilized both normal-hearing and hearing-impaired subjects. The subjects were tested under the same ear protection categories: 1) EAR Ultra 9000 2) MSA Noisefoe MarkII and 3) no earmuff. The broad band noise was presented at a constant level of 85 dBA while the sound pressure level of the speech stimuli was varied from 80 to 93 dBA (i.e., S/Ns of -5, 0, +6, and +8 dB). Again, the subjects gave written responses and word discrimination scores (% correct) were calculated.

RESULTS

Experiment I

Mean word discrimination scores were calculated for the normal-hearing subjects in the three earmuff conditions and plotted as a function of the noise sound pressure level in dBA in Figure 6. A one-factor ANOVA was used to compare the subjects' performances in the various earmuff conditions at each S/N ratio (See Appendix A for ANOVA data). At a S/N of +32 dB there was a significant difference in the subjects' word discrimination scores when the earmuff conditions were compared (Scheffe F-test). A comparison of the "no muff" condition with both the Ultra 9000 and the Mark II conditions showed that word discrimination scores were significantly decreased with the earmuffs in the lower level of noise and speech (Speech =68 dBA, Noise= 36 dBA). The mean differences, or mean decrease in word discrimination scores, were 8.5% ($p<.05$) for the Ultra 9000 earmuff and 18% ($p<.05$) for the Mark II earmuff. However, the comparison of the Ultra 9000 performance with the Mark II performance showed a 9.5% ($p<.05$) improvement in word discrimination score when the Ultra 9000 was used. At a S/N of +21 dB there was not a significant difference in word discrimination scores when comparing the "no muff" condition with the Ultra 9000 condition. Significant differences were also not found between the Ultra 9000 and Mark II conditions. There was, however, a significant difference between the "no muff" and Mark II conditions. There was a mean decrease in word discrimination score of 20.7% ($p<.05$) with the Mark II earmuffs. At a S/N of +11 dB there was not a significant difference in word discrimination scores when the "no muff" and Ultra 9000 conditions were compared. Again, a significant decrease of 26.3% ($p<.05$) in the word discrimination score was found when the "no muff" and Mark II conditions were compared. At S/N of +11 dB and -9 dB there were no significant differences between earmuff condition

Data for the normal-hearing and hearing-impaired subjects were compared by performing a two-factor ANOVA on the word discrimination scores obtained in the following conditions: 1) an average peak sound pressure level of the speech stimuli of 68 dBA and 2) a noise level of 36 dBA (ambient). (See Appendix B for the ANOVA data) The mean word discrimination scores are represented in Table 4. Hearing status and muff condition were significant ($p=.0001$). With the use of the Ultra 9000 earmuffs, there was a mean decrease in word discrimination score of 8.0% for the normal-hearing subjects and 22% for the hearing-impaired subjects when compared to the "no muff" condition. With the use of the Mark II earmuff, there was a mean decrease in word discrimination score of 18.3% for the normal-hearing subjects and 42.5% for the hearing-impaired subjects when compared to the "no muff" condition.

Experiment II

Word discrimination scores were calculated for the normal-hearing and hearing-impaired subjects from data gathered in Part B of the experiment (Noise= 85 dBA) and the mean scores were plotted as a function of S/N in Figures 7 and 8. A two-factor ANOVA was performed to compare hearing status and earmuff conditions. (See Appendix C for ANOVA data) The mean word discrimination scores were also organized by hearing status and earmuff condition in Table 5. At a S/N of -5 dB , no significant differences were found for the variables of hearing status or earmuff condition. At S/Ns of +1 dB, +6 dB, and +9 dB, only hearing status was found to be significant. No significant differences in word discrimination scores were found between the three earmuff conditions: 1) no muff 2) EAR Ultra 9000 or 3) MSA Noisefoe MarkII. There were no significant interactions.

DISCUSSION

The purpose of the present study was to evaluate word discrimination ability of normal-hearing and hearing-impaired subjects in a noisy, reverberant environment such as that found in many industrial situations. In particular, the performance of two different circumaural earmuffs was compared under two noise conditions in the normal-hearing and hearing impaired groups. The selection of normal-hearing and hearing-impaired subjects was intended to be representative of populations that are often found in industrial environments. Particular attention was given to the hearing threshold levels of the hearing-impaired group at frequencies above 2000 Hz, for previous data show a significant increase in hearing threshold levels for the higher frequencies in workers exposed to high levels of noise (Taylor and Pearson, 1965). The etiology of the hearing loss identified in the hearing-impaired group was not determined, but more than one-half of the subjects reported a positive history of noise exposure. Another contributing factor to the hearing loss found in this group might be the effect of aging on hearing threshold level, particularly the increased incidence of a loss in the higher frequencies.

The selection of a reverberant test booth was also intended to represent an environment that would be more likely to occur in an industrial setting. The broad band noise and speech stimuli were selected to represent a more difficult test situation which would accent any differences in the subjects' performances in the three earmuff conditions. The CID W-22 word lists were chosen because the stimuli are much harder to identify than multi-syllabic words or sentences (Hirsh, Reynolds, and Joseph, 1954). The redundancy and predictability of the speech message are reduced when monosyllables are used. It is true, however, that in normal communication contexts, we do not usually speak in single word utterances.

The results in Experiment I indicated that, at higher levels of noise (low S/N), the task became so difficult that the word discrimination scores with either earmuff were not significantly reduced over the "no muff" condition. The subjects performed poorly in all earmuff conditions at these low S/N ratios (+1 dB and +9 dB). However, as the noise level decreased (S/N high), there were significant differences found in the subjects' performances with the two earmuffs. The Ultra 9000 earmuff allowed higher word discrimination scores to be obtained than did the Mark II. These results suggest that the type of earmuff can have a significant effect on word discrimination ability. Thus, for normal-hearing listeners, wearing earmuffs causes a significant reduction in word discrimination ability in relatively low levels of noise, but not higher levels of noise because the task is inherently difficult.

The analysis of variance, comparing portions of the data from Experiment I for the normal-hearing and hearing-impaired groups, indicates that hearing status and earmuff condition are both significant main effects (See Appendix B). The subjects with high tone hearing losses performed more poorly both with and without the earmuffs than did the normals when listening to speech in the ambient noise (36 dBA). The type of earmuff used also seemed to make a difference in word discrimination scores. The "no muff" condition was the most favorable condition and represented a reference score for comparing the Ultra 9000 and Mark II earmuff performances. The mean scores of 89.7% and 64.0% (NH and HI) in the Ultra 9000 condition show that these earmuffs are better for understanding speech stimuli in the low noise environments than the Mark II earmuffs with mean scores of 79.4% and 43.5% (NH and HI).

One might ask why the earmuffs were tested in a noise environment that would not ordinarily require the use of an ear protector according to noise regulation standards. This portion of the experiment was carried out for the purpose of establishing a subject's baseline performance which facilitated other comparisons. There are situations in industry in which a worker spends the major portion of his time in relatively quiet noise environments (50-75 dBA), but because there is an unpredictable intermittent noise created by nearby machinery which surpasses noise regulation standards, hearing protection must be utilized. In this situation, it would be to the worker's advantage to wear an ear protection device that will allow him the best word discrimination ability in relative quiet and simultaneously provide adequate noise attenuation.

Applying the previously mentioned reasoning to the present study, the Ultra 9000 earmuff should be chosen over the Mark II earmuff because the Ultra 9000 allows higher word discrimination scores to be obtained by both types of subjects. A possible reason for the better performance with the Ultra 9000 may be that the real-ear attenuation values, as stated by the manufacturer (ANSI S3.12-1984), are generally lower for all test frequencies, with marked differences in the frequencies from 1000 to 8000 Hz. The consonants are more important for determining the structure of a word, and it is precisely these high frequency components of speech that are masked by the noise and attenuated by hearing protectors. With the Ultra 9000 earmuff, more high frequency information of the speech spectrum is allowed to pass to the subject's ear and results in a higher word discrimination score.

Experiment II of the study investigated word discrimination ability of the two subject groups in a more realistic industrial environment with a broad band noise level.of 85 dBA. The analysis of variance (See Appendix C) indicated that no significant differences were found at a S/N of -5 dB. This S/N represented an unfavorable listening condition for both normal-hearing and hearing-impaired subjects in all earmuff conditions. The groups performed equally as poor with mean word discrimination scores of only 13.7% and 8.0% for the "no muff" condition. Wearing earmuffs did not improve or significantly decrease the word discrimination scores of either group. When the performances of the normal-hearing and hearing-impaired groups were compared at S/Ns of +1 dB, +6 dB, and +8 dB, only hearing status was significant. In general, the hearing-impaired subjects performed more poorly at all of these S/Ns irrespective of muff condition.

The results from the present study do not agree with those quoted by Kryter (1946) which indicated that wearing ear protectors improved speech intelligibility for normal-hearing listeners in high levels of ambient noise. Interestingly, the highest mean word discrimination score was found in the normal-hearing group in the "no muff" condition (57.1%). Results reported here indicate that earmuffs do not produce significant decreases in the word discrimination scores of normal-hearing or hearing impaired listeners in high levels of ambient noise (85 dBA) when compared to the non-protected condition. There are, however, differences in scores obtained with particular protective devices, and these should be considered when selecting the most suitable device for an employee. For employees who have already developed a hearing loss, these results would suggest that a suitable hearing protector would be one that provides as little attenuation as possible and yet enough effective protection in high levels of ambient noise.

REFERENCES

Alberti, P.W.: Personal hearing protection in industry ,Raven Press, New York, 1982.

Berger, E.H.: The effects of hearing protectors on auditory communications. Sound and Vibration14 (1): 16-17, 1980.

Clark, W.W. and B.A. Bohne.: The effects of noise on hearing and the ear. J Family Med, 17-22, Dec, 1984.

Coles, R.R.A. and C.G. Rice.: Earplugs and impaired hearing. J Sound Vibr, 8, 521-523, 1965.

Deutsh, L.J. and B. Kruger.: The systematic selection of 25 monosyllables which predict the CID W-22 speech discrimination score. J Aud Res, 11, 286-290, 1971.

Feldman, A.S. and C.T. Grimes.: Hearing Conservation in Industry, Williams & Wilkins, Baltimore, 1985.

French, N.R. and J.C. Steinberg.: Factors governing the intelligibility of speech sounds. J Acoust Soc Am, Vol. 19, No. 1, 1947.

Hirsh, I.J. and W.D. Bowman.: Masking of speech by bands of noise. J Acoust Soc Am, Vol. 25, No. 6, 1175-1180, 1953.

Hirsh, I.J., G. Reynolds and M. Joseph.: Intelligibility of different speech materials. J Acoust Soc Am, Vol. 26, No. 4, 530-538, 1954.

Kryter, K.D.: Effects of ear protective devices on the intelligibility of speech in noise. J Acoust Soc Am, Vol. 18, No. 2, 413-417, 1946.

Kryter, K.D.: The effects of noise on man (2nd ed.), Academic Press, Orlando, 1985.

Lempert, B.: Compendium of hearing protection devices. Sound and Vibration 18 (5) 26-39, 1984.

Lindeman, H.E.: Speech intelligibility and the use of hearing protectors. Audiology, Vol. 15, 348-356, 1976.

Penrod, J.P.: A comparison of half-list vs. full-list speech discrimination scores in a hearing-impaired geriatric population. J Aud Res, 20, 181-186, 1980.

Rink, T.L.: Hearing protection and speech discrimination in hearing-impaired persons. Sound and Vibration 13(1): 22, 1979.

Taylor, W., Pearson, J., et al.: Study of noise and hearing in jute weaving. J Acoust Soc Am,, Vol. 38, 113-120, 1965.

Walker, G., H. Dillion, and D. Byrne.: Sound field audiometry: recommended stimuli procedures. Ear and Hearing, Vol. 5, No. 1, 13-21, 1984

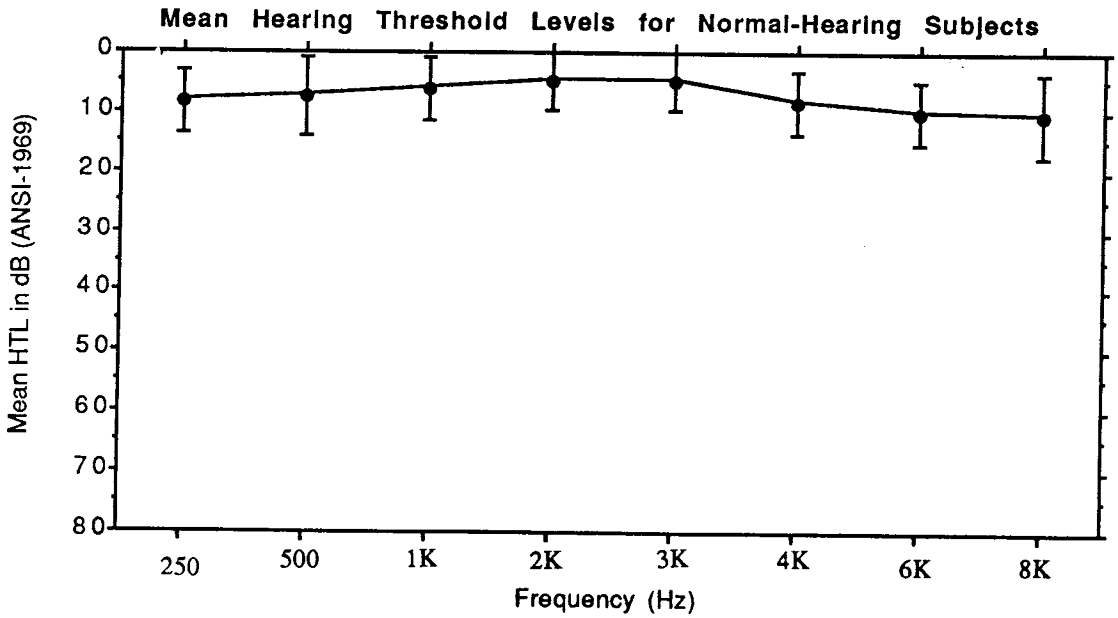
Wilkins, P.A. and A.M. Martin.: "The effects of hearing protection on the perception of warning sounds," in Alberti, P.W. (ed.) Personal Hearing Protection in Industry, Raven Press, New York, 1982.

TABLE 1

Mean Hearing Threshold Levels for Normal-Hearing Subjects

Frequency (Hz)	Mean	Std. Dev.	Range
250	8.1	5.3	0-15
500	7.5	6.4	0-20
1000	6.3	5.2	0-15
2000	5.0	4.6	0-10
3000	5.0	4.6	0-10
4000	8.1	5.3	0-15
6000	10.0	5.3	5-20
8000	11.9	5.3	5-20

FIGURE 1



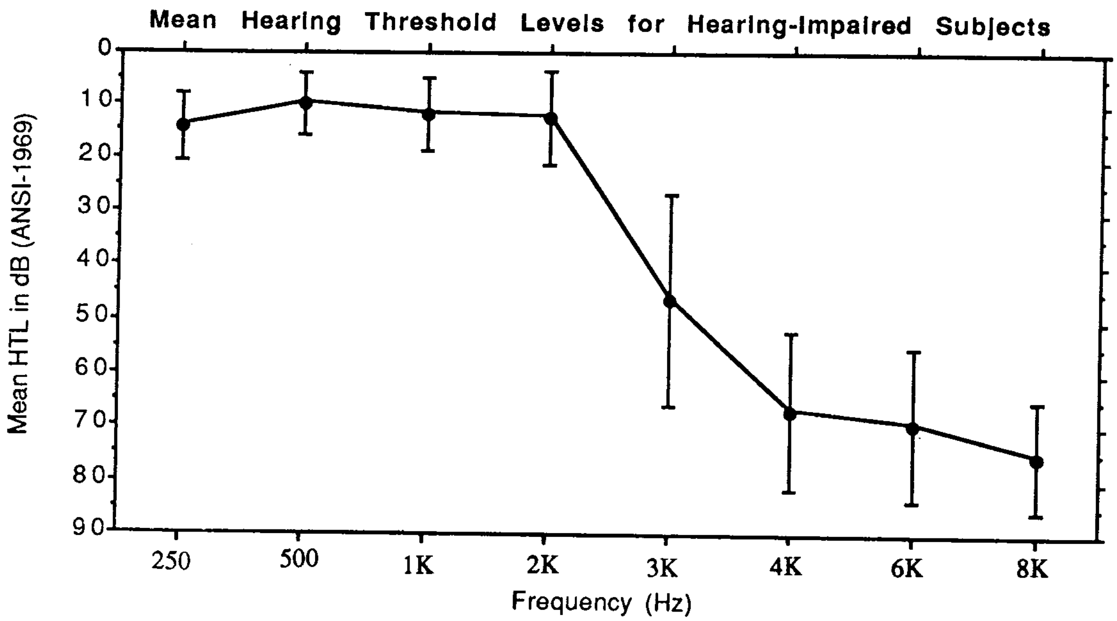
Mean Hearing Threshold Levels for Normal-Hearing Subjects
Mean HTL in dB (ANSI-1969)
0
10
20
30
40
50
60
70
80
250
500
1K
2K
3K
4K
6K
8K
Frequency (Hz)

TABLE 2

Mean Hearing Threshold Levels for Hearing-Impaired Subjects

Frequency(Hz)	Mean	Std. Dev.	Range
250	14.2	6.24	5-25
500	9.7	5.8	0-25
1000	11.6	7.07	5-35
2000	12.2	8.8	0-30
3000	45.8	19.5	15-80
4000	66.7	14.7	40-90
6000	69.2	14.1	40-90
8000	75	10.4	55-100

FIGURE 2



Mean Hearing Threshold Levels for Hearing-Impaired Subjects
Mean HTL in dB (ANSI-1969)
0
10
20
30
40
50
60
70
80
90
250
500
1K
2K
3K
4K
6K
8K
Frequency (Hz)

FIGURE 3

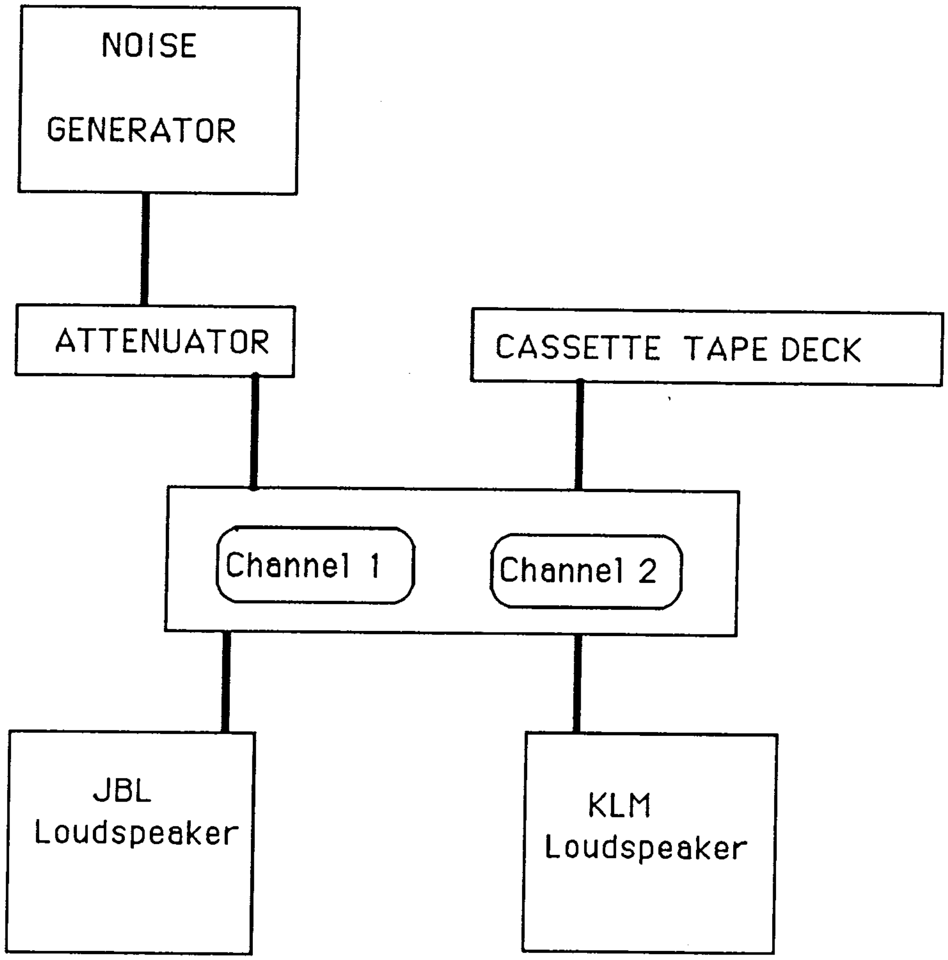

NOISE
GENERATOR
ATTENUATOR
CASSETTE TAPE DECK
Channel 1
Channel 2
JBL
Loudspeaker
KLM
Loudspeaker

FIGURE 4

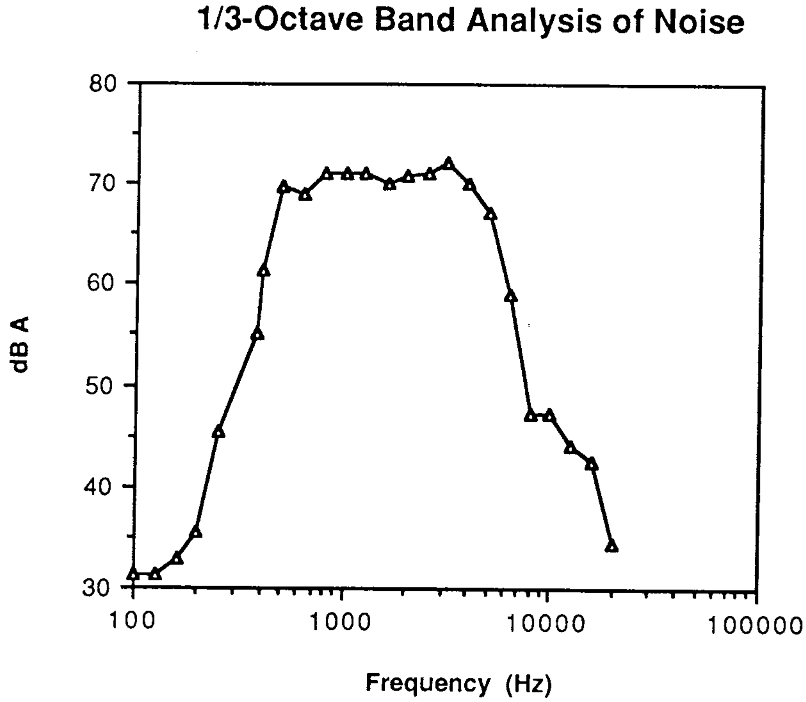
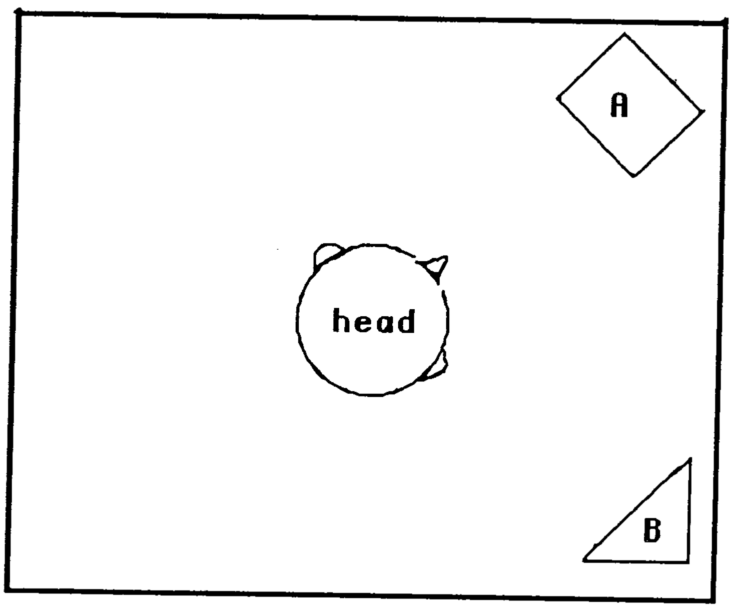

1/3-Octave Band Analysis of Noise
80
70
60
50
40
30
dB A
100
1000
10000
100000
Frequency (Hz)

TABLE 3

Average Real-Ear Attenuation in dB vs. Frequency in Hz
(Standard Deviation in dB)

	NRR	125	250	500	1000	2000	3150	4000	6300	8000 Hz
EAR Ultra 9000										
	15 dB	10.7 (3.9)	15.4 (3.1)	26.4 (2.7)	24.1 (2.7)	23.3 (2.4)	26.7 (3.3)	24.4 (2.7)	23.4 (2.3)	25.3 (2.4)
Noisefoe MarkII										
	25 dB	15 (2.2)	21 (1.8)	29 (2.0)	35 (1.6)	37 (2.1)	37 (1.9)	37 (2.4)	37 (3.1)	36 (2.2)

FIGURE 5



A = KLM Loudspeaker
B = JBL Loudspeaker

FIGURE 6

Mean Word Discrimination Scores for Normal-Hearing Subjects in Three Earmuff Conditions (Peak Speech SPL= 68 dB A)

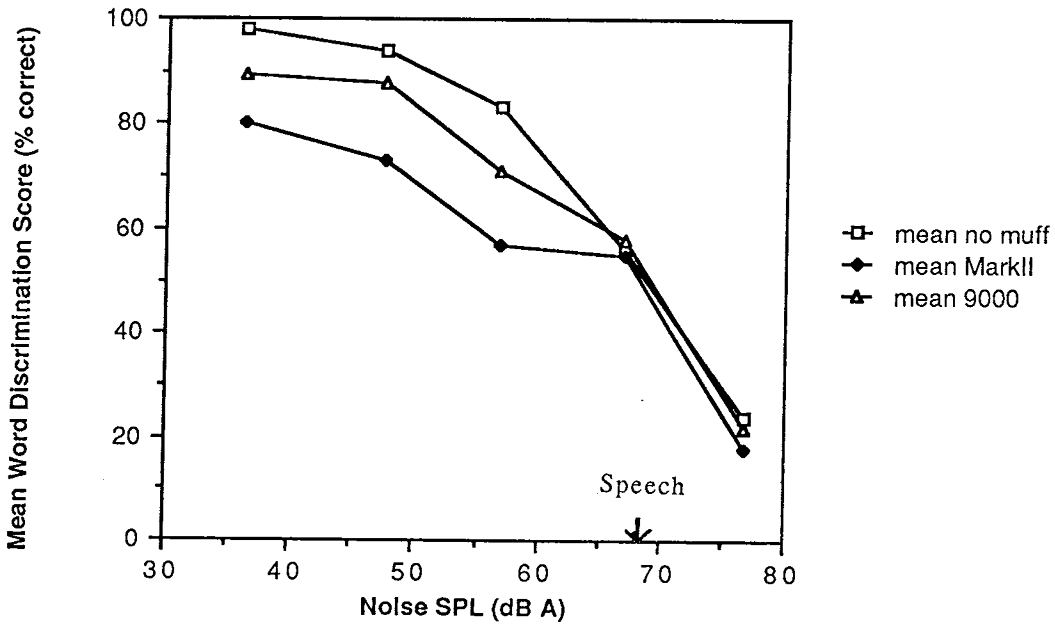


TABLE 4

MEAN WORD DISCRIMINATION SCORES OF NORMAL AND HEARING-IMPAIRED SUBJECTS IN THREE EARMUFF CONDITIONS (S/N = +32, PEAK SPEECH SPL= 68 dB A)

	NO MUFF	ULTRA 9000	MARK II
NH	97.7	89.7	79.4
HI	86.0	64.0	43.5

* HEARING STATUS SIGNIFICANT (p= .0001)

* MUFF TYPE SIGNIFICANT (p= .0001)

* SIGNIFICANT INTERACTION (p= .0029)

FIGURE 7

Word Discrimination Scores of Normal-Hearing Subjects in Three Earmuff Conditions (85 dB A Noise)

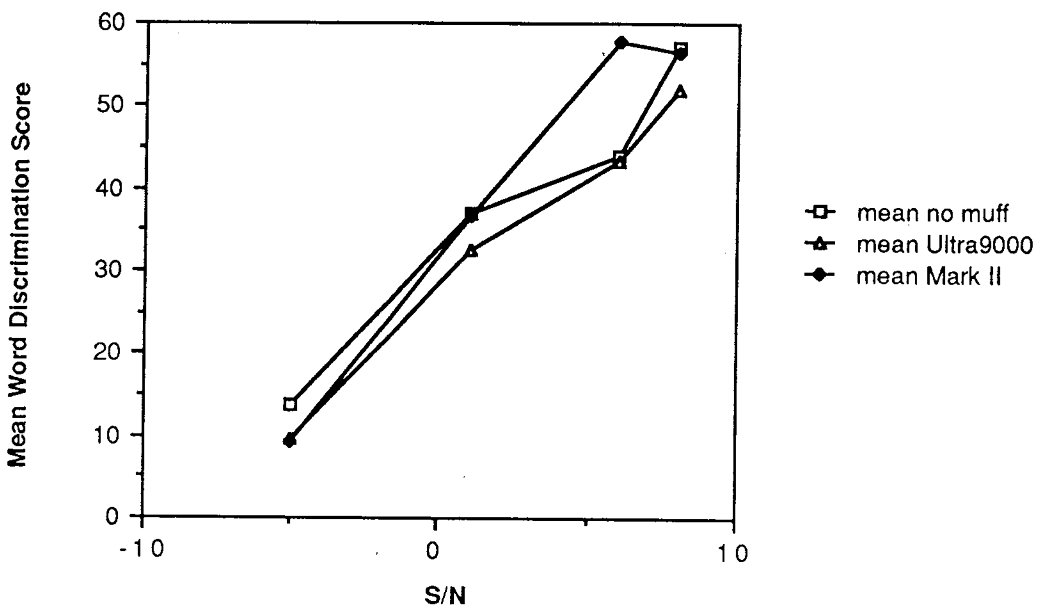


FIGURE 8

Word Discrimination Scores of Hearing-Impaired Subjects in Three Earmuff Conditions (85 dB A Noise)

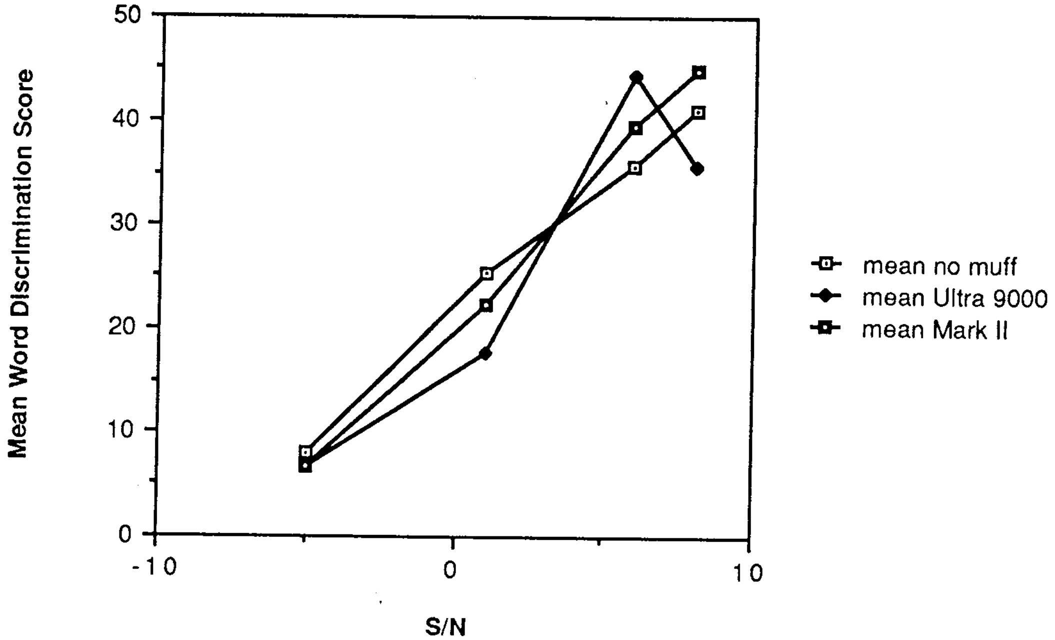


TABLE 5

MEAN WORD DISCRIMINATION SCORES OF NORMAL AND HEARING-IMPAIRED SUBJECTS IN THREE EARMUFF CONDITIONS (85 dB A NOISE)

S/N = -5

*NO SIGNIFICANT DIFFERENCES

	NO MUFF	ULTRA 9000	MARK II
NH	13.7	9.7	9.1
HI	8.0	6.7	6.7

S/N = +1

* HEARING STATUS SIGNIFICANT (p= .0001)

	NO MUFF	ULTRA 9000	MARK II
NH	37.1	32.6	36.6
HI	25.3	17.8	22.2

S/N = +6

* HEARING STATUS SIGNIFICANT (p= .0151)

	NO MUFF	ULTRA 9000	MARK II
NH	44.0	43.4	57.7
HI	35.6	44.4	39.6

S/N = +8

* HEARING STATUS SIGNIFICANT (p= .0002)

	NO MUFF	ULTRA 9000	MARK II
NH	57.1	52.0	56.6
HI	40.9	35.6	44.9

APPENDIX A

One Factor ANOVA X_1: mufftype Y_1: WDS 36.2

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	1297.333	648.667	16.412
Within groups	21	830	39.524	p = .0001
Total	23	2127.333		

Model II estimate of between component variance = 304.571

One Factor ANOVA X_1: mufftype Y_1: WDS 36.2

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
no	8	98	3.024	1.069
Ultra 9000	8	89.5	6.024	2.13
Mark II	8	80	8.552	3.024

One Factor ANOVA X_1: mufftype Y_1: WDS 36.2

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
no vs. Ultra 9000	8.5	6.538*	3.656*	2.704
no vs. Mark II	18	6.538*	16.395*	5.726
Ultra 9000 vs. Mark II	9.5	6.538*	4.567*	3.022

* Significant at 95%

One Factor ANOVA X_1: mufftype Y_2: WDS 47.6

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	749.333	374.667	7.565
Within groups	7	346.667	49.524	p = .0178
Total	9	1096		

Model II estimate of between component variance = 162.571

One Factor ANOVA X_1: mufftype Y_2: WDS 47.6

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
no	4	94	2.309	1.155
Ultra 9000	3	88	4	2.309
Mark II	3	73.333	12.22	7.055

One Factor ANOVA X_1: mufftype Y_2: WDS 47.6

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
no vs. Ultra 9000	6	12.711	.623	1.116
no vs. Mark II	20.667	12.711*	7.392*	3.845
Ultra 9000 vs. Mark II	14.667	13.589*	3.258	2.553

* Significant at 95%

One Factor ANOVA X_1: mufftype Y_3: WDS 56.8

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	1728.333	864.167	4.862
Within groups	13	2310.667	177.744	p = .0265
Total	15	4039		

Model II estimate of between component variance = 343.212

One Factor ANOVA X_1: mufftype Y_3: WDS 56.8

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
no	4	83	11.015	5.508
Ultra 9000	6	71.333	12.754	5.207
Mark II	6	56.667	15.055	6.146

One Factor ANOVA X_1: mufftype Y_3: WDS 56.8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
no vs. Ultra 9000	11.667	18.594	.919	1.356
no vs. Mark II	26.333	18.594*	4.682*	3.06
Ultra 9000 vs. Mark II	14.667	16.631	1.815	1.905

* Significant at 95%

One Factor ANOVA X_1: mufftype Y_4: WDS 67

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	18.667	9.333	.027
Within groups	9	3164	351.556	p = .9739
Total	11	3182.667		

Model II estimate of between component variance = -171.111

One Factor ANOVA X_1: mufftype Y_4: WDS 67

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
no	4	56	22.39	11.195
Ultra 9000	4	58	18.037	9.018
Mark II	4	55	15.1	7.55

One Factor ANOVA X_1: mufftype Y_4: WDS 67

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
no vs. Ultra 9000	-2	29.996	.011	.151
no vs. Mark II	1	29.996	.003	.075
Ultra 9000 vs. Mark II	3	29.996	.026	.226

One Factor ANOVA X_1: mufftype Y_5: WDS 76.8

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	78.933	39.467	.099
Within groups	12	4774.4	397.867	p = .9063
Total	14	4853.333		

Model II estimate of between component variance = -179.2

One Factor ANOVA X_1: mufftype Y_5: WDS 76.8

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
no	5	24	12.329	5.514
Ultra 9000	5	21.6	28.369	12.687
Mark II	5	18.4	15.388	6.882

One Factor ANOVA X_1: mufftype Y_5: WDS 76.8

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
no vs. Ultra 9000	2.4	27.49	.018	.19
no vs. Mark II	5.6	27.49	.099	.444
Ultra 9000 vs. Mark II	3.2	27.49	.032	.254

APPENDIX B

Anova table for a 2-factor Analysis of Variance on Y_1: #1 WDS%S/N 32

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
HEARING STATUS (A)	1	6696.692	6696.692	82.791	.0001
MUFF TYPE (B)	2	6897.537	3448.768	42.637	.0001
AB	2	1103.403	551.702	6.821	.0029
Error	39	3154.571	80.886		

There were no missing cells found.

The AB Incidence table on Y_1: #1 WDS%S/N 32

	MUFF TYPE:	Ultra 9000	no	MarkII	Totals:
HEARING...	NH	7	7	7	21
		89.714	97.714	79.429	88.952
	HI	8	8	8	24
		64	86	43.5	64.5
Totals:		15	15	15	45
		76	91.467	60.267	75.911

APPENDIX C

Anova table for a 2-factor Analysis of Variance on Y_1: WDS % -5

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
HEARING STATUS (A)	1	165.762	165.762	3.377	.0732
MUFF TYPE (B)	2	83.524	41.762	.851	.4343
AB	2	23.524	11.762	.24	.788
Error	42	2061.714	49.088		

There were no missing cells found.

The AB Incidence table on Y_1: WDS % -5

	MUFF TYPE:	Ultra 9000	no	MarkII	Totals:
HEARING...	NH	7 9.714	7 13.714	7 9.143	21 10.857
HEARING...	HI	9 6.667	9 8	9 6.667	27 7.111
Totals:		16 8	16 10.5	16 7.75	48 8.75

Anova table for a 2-factor Analysis of Variance on Y_1: WDS % +1

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
HEARING STATUS (A)	1	2201.19	2201.19	31.473	.0001
MUFF TYPE (B)	2	304.413	152.206	2.176	.1261
AB	2	20.413	10.206	.146	.8647
Error	42	2937.397	69.938		

There were no missing cells found.

The AB Incidence table on Y_1: WDS % +1

	MUFF TYPE:	Ultra 9000	no	MarkII	Totals:
HEARING...	NH	7 32.571	7 37.143	7 36.571	21 35.429
	HI	9 17.778	9 25.333	9 22.222	27 21.778
Totals:		16 24.25	16 30.5	16 28.5	48 27.75

Anova table for a 2-factor Analysis of Variance on Y_1: WDS % +6

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
HEARING STATUS (A)	1	859.307	859.307	6.422	.0151
MUFF TYPE (B)	2	618.55	309.275	2.311	.1116
AB	2	723.884	361.942	2.705	.0785
Error	42	5619.81	133.805		

There were no missing cells found.

The AB Incidence table on Y_1: WDS % +6

	MUFF TYPE:	Ultra 9000	no	MarkII	Totals:
HEARING...	NH	7 43.429	7 44	7 57.714	21 48.381
	HI	9 44.444	9 35.556	9 39.556	27 39.852
Totals:		16 44	16 39.25	16 47.5	48 43.583

Anova table for a 2-factor Analysis of Variance on Y_1: WDS % +8

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
HEARING STATUS (A)	1	2585.19	2585.19	16.07	.0002
MUFF TYPE (B)	2	197.238	98.619	.613	.5465
AB	2	273.238	136.619	.849	.4349
Error	42	6756.571	160.871		

There were no missing cells found.

The AB Incidence table on Y_1: WDS % +8

	MUFF TYPE:	Ultra 9000	no	MarkII	Totals:
HEARING:	NH	7 52	7 57.143	7 56.571	21 55.238
HEARING:	HI	9 40.889	9 35.556	9 44.889	27 40.444
Totals:		16 45.75	16 45	16 50	48 46.917